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The Atlantic Coast of Maryland, Sediment Budget Update: Tier 2, Assateague Island and Ocean City Inlet

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PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) describes a Regional Sediment Management (RSM) strategy developed to update a holistic sediment budget for the portion of the Atlantic Ocean shoreline within the U.S. Army Corps of Engineers (USACE) Baltimore District's Area of Responsibility, which for coastal applications is the Maryland coast bounded by Delaware to the north and Virginia to the south. Active Federal projects existing within the limits of this task include the Atlantic Coast of Maryland Shoreline Protection Project, the Assateague Island ecosystem restoration project, Stinky Beach (Section 111 – Rivers and Harbors Act), the navigational structures at the Ocean City Inlet, and a number of Federally authorized channels (Figure 1). Reed (2014) reported on the first tier of the study in the area of interest, which included the Atlantic Coast of Maryland Shoreline Protection Project, the shoreline north of Ocean City Inlet extending to the Maryland/Delaware border. This CHETN addresses the remainder of the coastline, including Assateague Island and Ocean City Inlet. This effort was supported by the USACE Baltimore District (NAB) and the USACE Engineer Research and Development Center (ERDC) Coastal and Hydraulics Laboratory (CHL) through the USACE RSM Program. This CHETN documents the purpose, development, and outcomes of the second tier in the Atlantic Coast of Maryland Sediment Budget Update to develop a regional sediment budget for the mid-Atlantic coastal zone.

INTRODUCTION: The approximately 31 miles of coastline fronting the Atlantic Ocean within the state of Maryland consist of barrier islands separated by Ocean City inlet. Since the inlet originally formed in 1933, anthropogenic effects have been proliferated in the form of inlet dredging, shoreline armoring, and placement of offshore borrow material on the shoreline. Over the past few years, several sediment budgets have been created to identify sources, sinks, and sediment pathways. The most recent of these budgets covered the 1995 to 2002 and 2004 to 2008 epochs (Offshore and Coastal Technologies, Inc. [OCTI] 2011), leaving the most recent 5 years (2008 to 2013) unaccounted. Reoccurring engineering activities in the area include berm reconstruction (beach renourishment) at the Atlantic Coast of Maryland Shoreline Protection Project over approximately 4-year intervals, biannual manual bypassing of sediment from the ebb/flood shoal to Assateague Island, and periodic maintenance of the Federally authorized navigation channels.

METHOD: The goal of the RSM program is to change the USACE focus from managing sediments and projects on a local scale to taking a systems approach to deliberately manage sediments in a manner that maximizes natural and economic efficiencies to contribute to sustainable water resource projects, environments, and communities. The key objectives are to (1) recognize sediment as a valuable resource, (2) implement regional strategies across multiple projects and business lines to guide investments to achieve long-term economic, environmental, and social value and benefits, (3) enhance relationships with stakeholders and partners to better

manage sediments across a region (local actions with regional benefits), and (4) share lessons learned, data, tools, and technology[1]. In an area where so many anthropogenic activities are being undertaken, it is the goal of the Project Delivery Team (PDT), to maximize the placement of material so that it is placed in the utmost efficient manner. It is also the intent of the PDT to determine how engineering activities are affecting the natural sediment movement in the area.

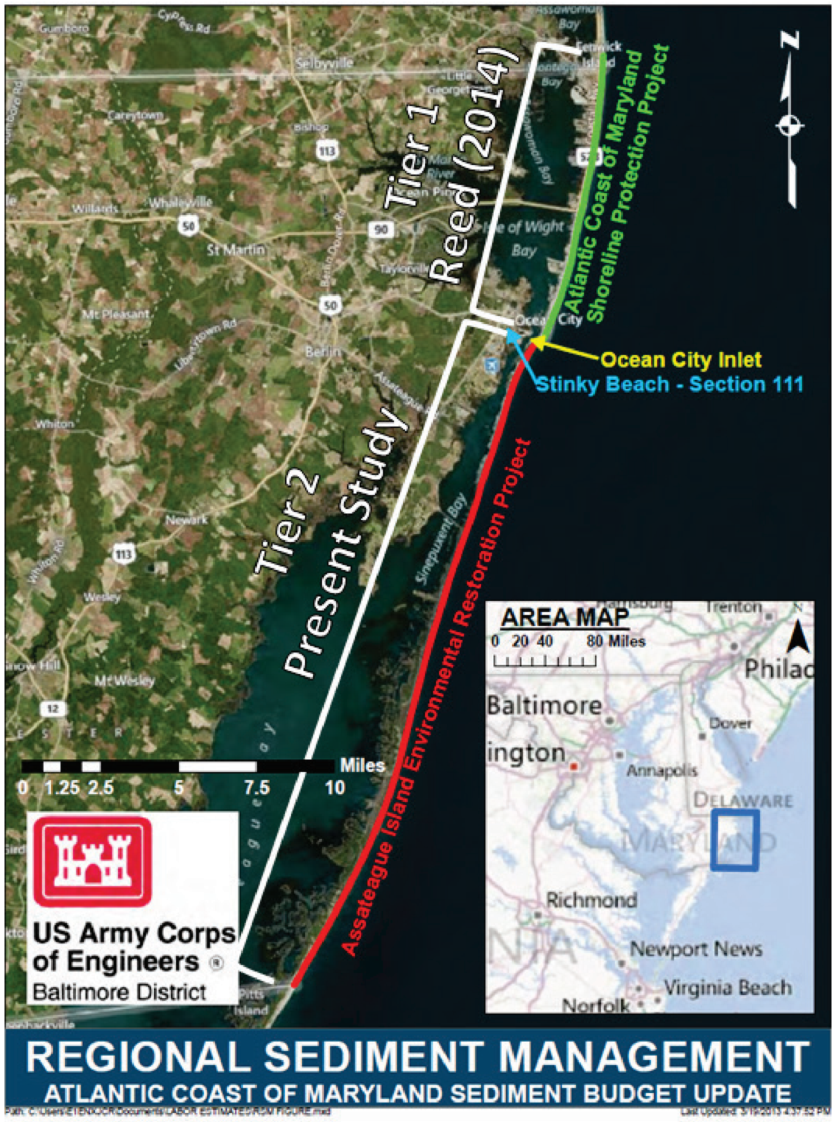

Figure 1. Active USACE Baltimore District projects within the area of interest.

The second tier of the study incorporates the sediment budget of Ocean City Inlet and Assateague Island into the Atlantic Coast of Maryland Shoreline Protection Project sediment budget developed under tier 1 and discussed by Reed (2014). Two alternatives concerning the direction of transport at the northern boundary of NAB's area of responsibility (near the

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[1] http://rsm.usace.army.mil

Maryland/Delaware State Line) were considered by Reed. Alternative 1 assumed that sand was transported north in the northernmost cell, and Alternative 2 assumed that no sand was transported north and that all sand is transported to the south. The sediment budget for Alternative 2 of the Atlantic Coast of Maryland Shoreline Protection Project was used as the northern boundary condition for the present analysis to link the Tier 1 budget with the current Tier 2 budget update. The Tier 1 budget provides a flux of approximately 183,000 cubic yards per year (yd^3/yr) of material from Ocean City beach into the inlet system. The sediment budget of the present study was calculated from multibeam surveys performed in Ocean City Inlet and from volumetric analyses of beach profile surveys at Assateague Island. Results from these analyses were imported into the stand-alone version of the Sediment Budget Analysis System (SBAS) (Rosati and Kraus 1999, 2001; Dopsovic et al. 2002; Podoski 2013). The analysis methods and design of the SBAS cells are discussed below.

Ocean City Inlet. The inlet was divided into a 29-cell grid (Figure 2) by NAB that represented borrow areas for beach placement on Assateague Island and Fenwick Island. Multibeam surveys of the inlet with horizontal resolution of 5 feet (ft) were taken each fiscal year between 2008 and 2014. Points from each survey were interpolated onto a common 5 ft, uniformly spaced grid. Elevation differences between surveys were integrated over the area of each respective cell to determine volume change. Elevation differences in the inlet for the October 2008 to February 2014 are shown in Figure 3.

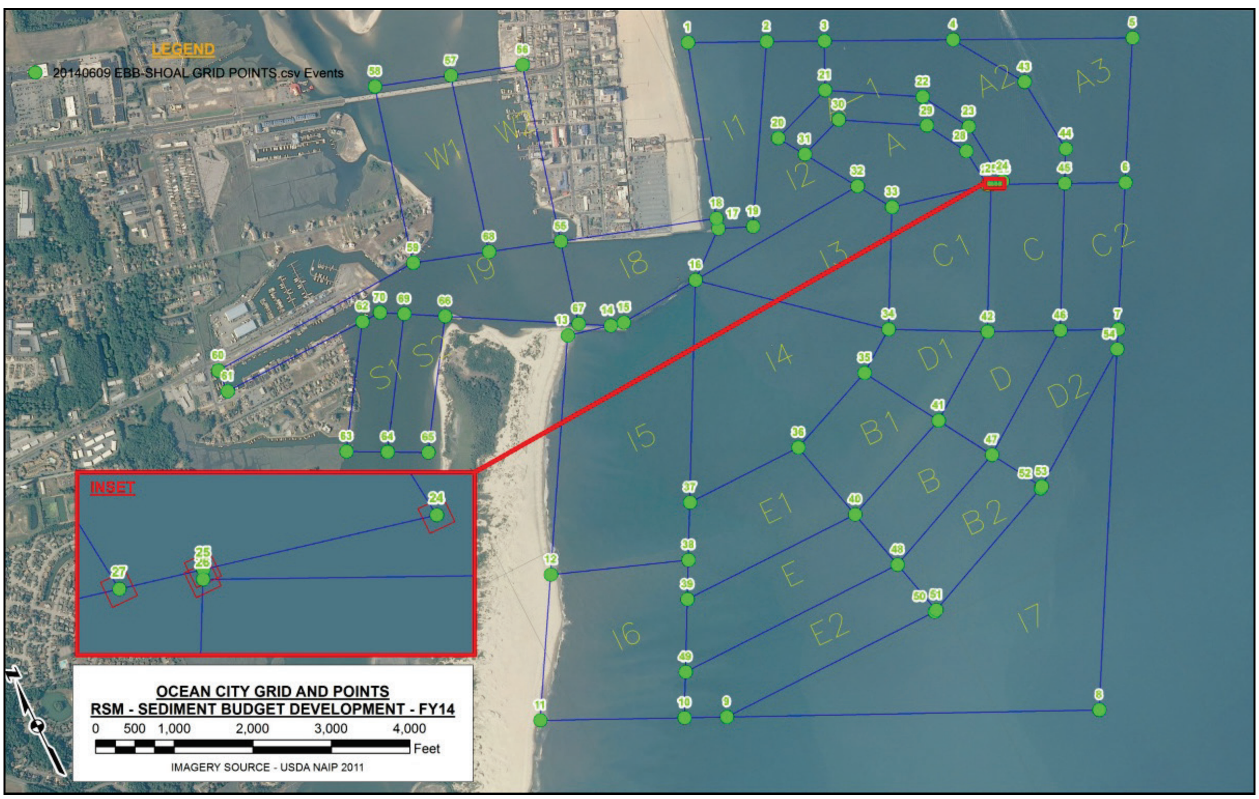


Figure 2. Ocean City Inlet borrow area grid.

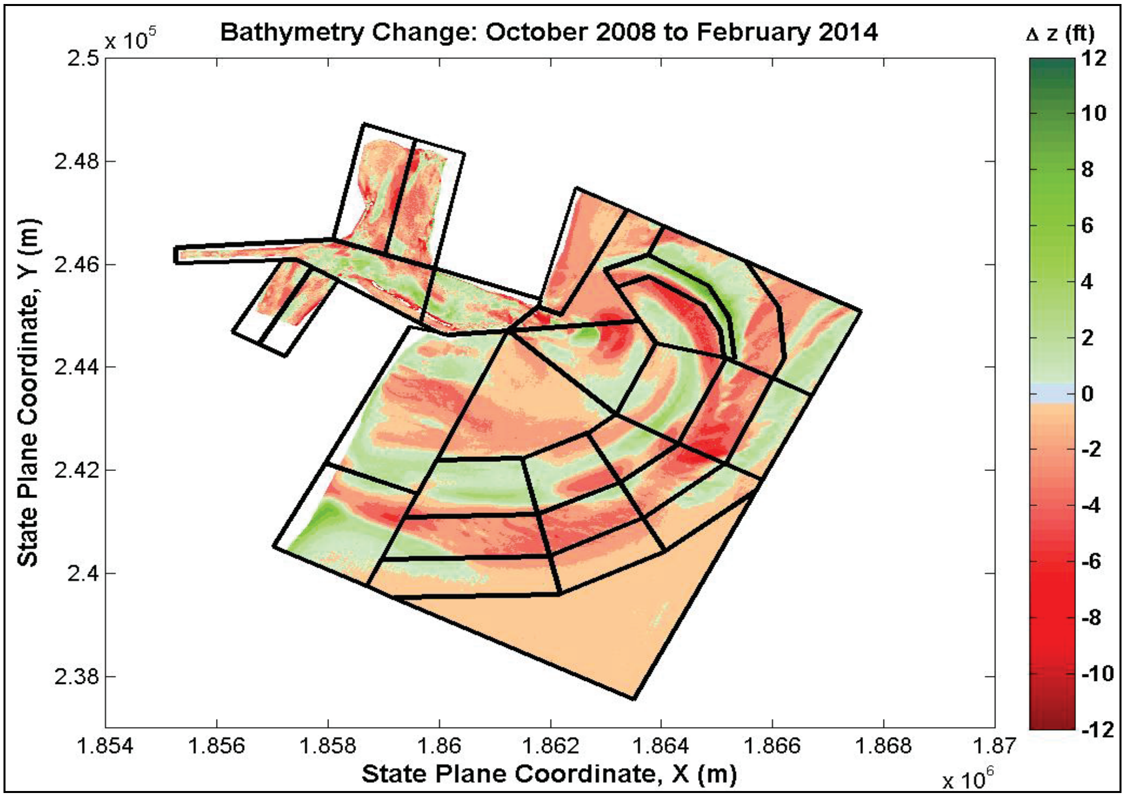


Figure 3. Inlet bathymetry change.

Volumetric changes from the 29 inlet cells were aggregated into 5 cells in SBAS. All ebb-shoal volumes and all inlet volumes were combined into respective cells. A cell consisting of inlet cells I3 and I4 was constructed between the ebb shoal and Assateague Island. Two SBAS cells were created on northern Assateague Island in which coverage of the multibeam surveys and the northernmost Assateague Island beach profiles overlapped. All volumes from the multibeam surveys were used for these cells, and beach profile volumes were used in areas where the multibeam data did not encompass the SBAS cells. Assateague Island beach profile volumes between AI1 and AI3 (Figure 4) were included with volumes from inlet cell I5, and profile volumes between AI3 and AI4 were combined with inlet cell I6.

Assateague Island. Beach profiles of Assateague Island are collected annually as part of NAB monitoring efforts. The 29 profiles (Figure 4) are currently surveyed from the bayside of the island past the depth of closure (the theoretical limit where there is no significant net cross-shore transport), with exception to the three northernmost profiles (AI1 to AI3), where depths are shallower due to the ebb shoal. However, the earlier datasets in the epoch do not extend to the bayside of the island but rather partway through the island to the monitoring baseline.

Volume change between profiles was calculated for the 2008–2013 epoch by comparing the 29 profiles for both years with the Beach Morphology Analysis Package (BMAP) (Sommerfeld et al. 1993, 1994; Wise 1995) as contained in the Coastal Engineering Design and Analysis System (CEDAS). The SBAS cells on Assateague Island were created as discrete compartments between each beach profile. Volume change for each cell was calculated by multiplying the average volume change between adjacent transects by the distance between transects.

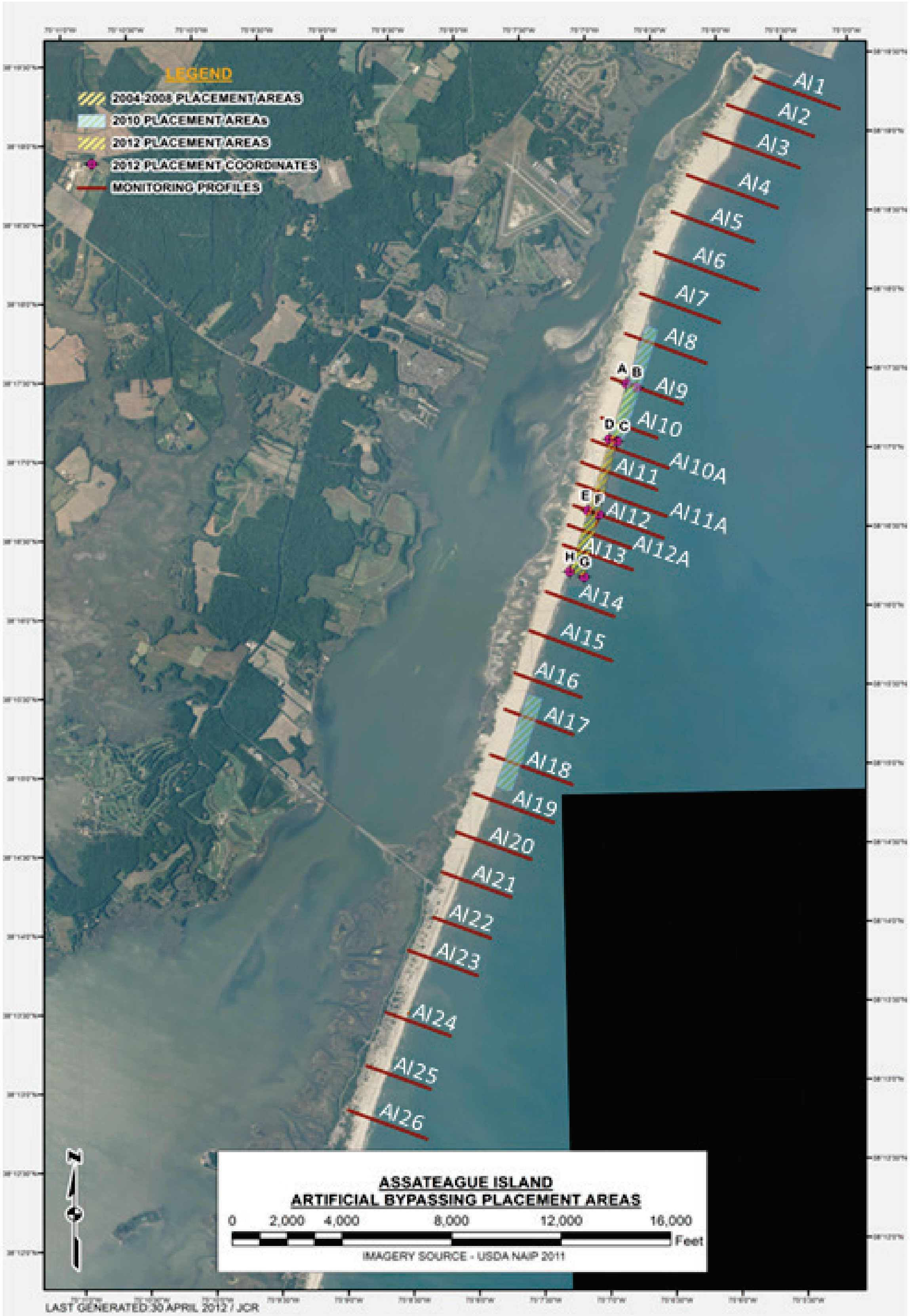


Figure 4. Assateague Island profile lines.

Figure 5 shows calculated volume changes with volume of material placed during the 10 manual bypassing events between 15 Mar 2009 and 31 Oct 2013. The figure shows large overall net losses of material in the majority of the cells. The placement of sand in several of the cells decreased the net volume loss and caused net volume gains in Cells 43 and 44. Altogether, approximately 662,000 yd^3, or 132,000 yd^3/yr, of sediment were manually bypassed during this epoch.

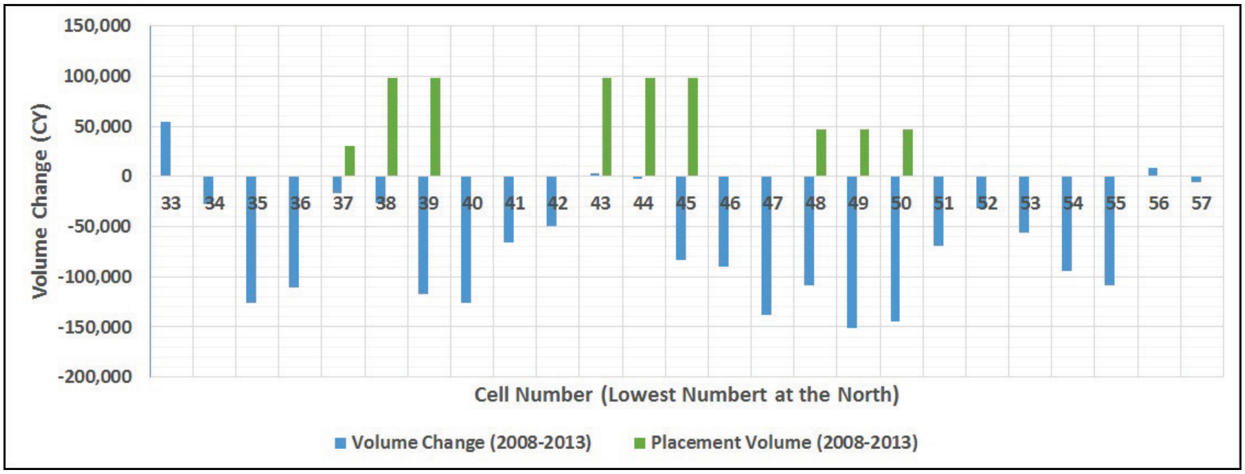


Figure 5. Volume change and placements at Assateague Island during the 2008 to 2013 epoch.

Figure 5 shows the *end-point* volume change over the 2008–2013 epoch, the change in volume between the beginning and end of the epoch. By including the erosion or accretion of the material placed during the manual bypassing events with the end-point volume change and converting the resulting volumes to an annual change per linear foot of beach, erosional hotspots can be identified. For the purposes of this CHETN, an erosional hotspot is defined as a section of the beach that erodes at a higher rate than the remainder of the shoreline (Kraus and Galgano 2001). The general equation used to arrive at the erosional rates in units of cubic yards per foot per year is

$$VC_{lf} = \frac{\frac{VC - P + R}{L}}{T} \tag{1}$$

in which VC_{lf} is annualized volume change per linear foot, VC is volumetric change in cubic yards calculated from end-point analysis of beach profile surveys, P is placement in cubic yards during the manual bypassing events from USACE records, R is removal in cubic yards from USACE records, L is length in linear feet between beach profile surveys (cell length), and T is time between start and end of the epoch and 5 years for the present analysis.

The annualized volume change per linear foot of beach shown in Figure 6 includes the loss of the material that was placed during the manual bypassing events and the end-point volume change. Erosional and depositional trends over the 2008–2013 epoch are evident, with erosion being evident along most of the island, except directly downdrift (south) of the attachment bar of the ebb shoal.

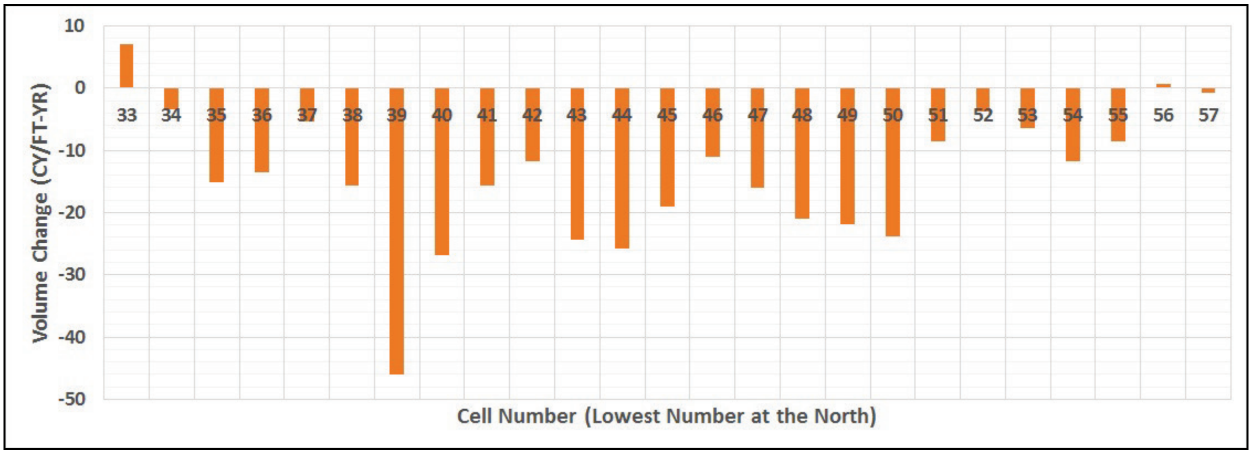


Figure 6. Annualized volume change per linear foot at Assateague Island.

RESULTS: The sediment budgets for Ocean City Inlet and Assateague Island were incorporated into the Atlantic Coast of Maryland Shoreline Protection Project Alternative 2 sediment budget, north of Ocean City Inlet, discussed by Reed (2014). The end loss at the southern boundary (approximately 183,000 yd^3/yr) of the Atlantic Coast of Maryland Shoreline Protection Project sediment budget provided a source of material into the inlet system. The present sediment budget includes removal of material from dredging the ebb and flood shoals in Ocean City Inlet and placement of material onto the Assateague Island beaches. However, material lost from the Assateague Island beaches by dune overwash is not included in the sediment budget because survey data were not available to perform the analysis.

The sediment budget of the inlet consisted of volumetric change for each cell derived from multibeam survey datasets, as well as the volume of material dredged from the ebb shoal and inlet (Figure 7). Cells that had a net gain in volume over the epoch are shown in green, and cells that had a net loss in volume are shown in red. Volume change (dV) is given in cubic yards per year (yd^3/yr) as are fluxes between cells (blue arrows), placements (P), and removals (R). Figure 7 shows that the ebb shoal (Cell 28), the inlet (Cell 30), and the region between the ebb shoal and northern Assateague Island (Cell 29) all had a net volumetric loss of volume over the epoch. However, the ebb shoal and inlet were both dredged to provide material to neighboring beaches. Table 1 lists the net volumetric changes in the inlet, placements, removal, and the adjusted volumetric change due to dredging. During the epoch, 413,200 yd^3 (82,600 yd^3/yr) were dredged from the ebb shoal (Cell 28), of which 1,000 yd^3 (200 yd^3/yr) were returned, and 273,200 yd^3 (54,600 yd^3/yr) were dredged from the flood shoal (Cell 30). Adjusting the volumetric changes derived from the multibeam surveys of the inlet and the accounting for material dredged during the epoch (686,400 yd^3), the ebb-shoal system (Cells 28 to 32) gained 772,900 yd^3. Specifically, Cells 28 and 30 had a net loss of 247,600 and 137,900 yd^3 respectively, but if the impact of dredging is included, the cells have a growth rate of 164,500 and 135,300 yd^3/yr, respectively.

A rate of 139,800 yd^3/yr bypassed the ebb shoal to Assateague Island, where the three northernmost cells on the island gained volume over the epoch. It was assumed material from the ebb shoal was transported to Cell 32 (Figure 7), which was the source of sediment for Cell 31 to the north and Cell 33 to the south.

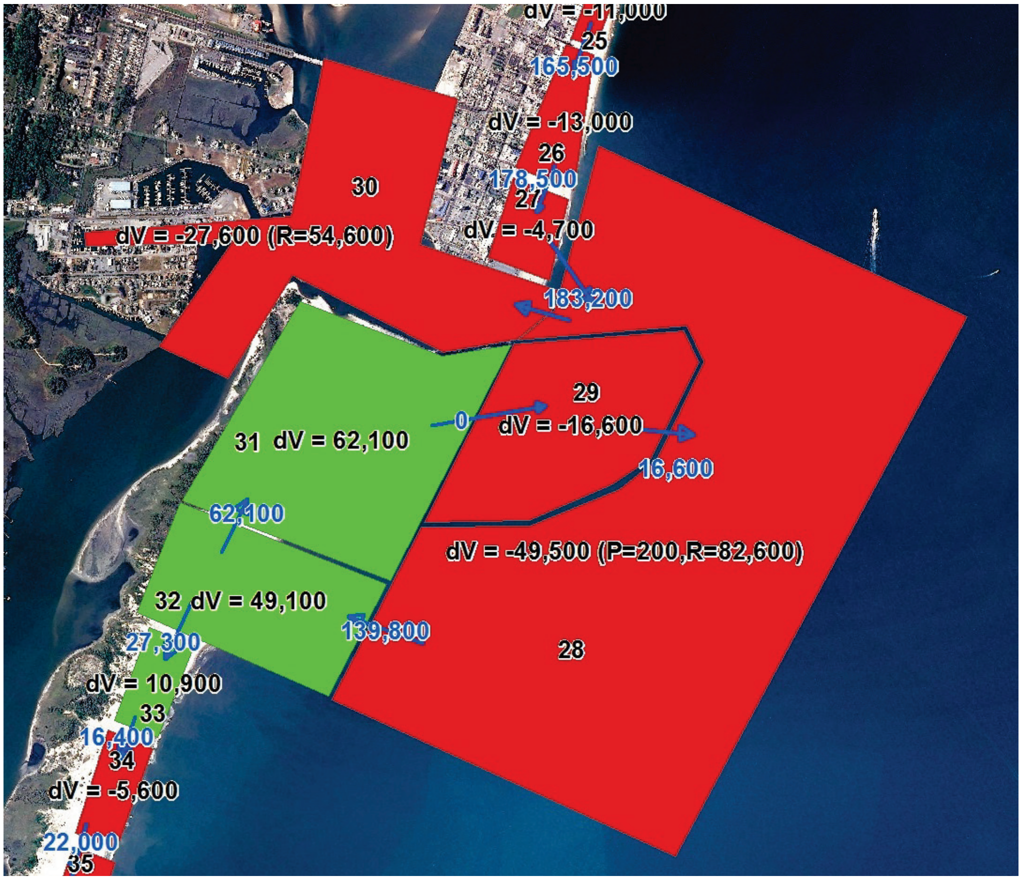


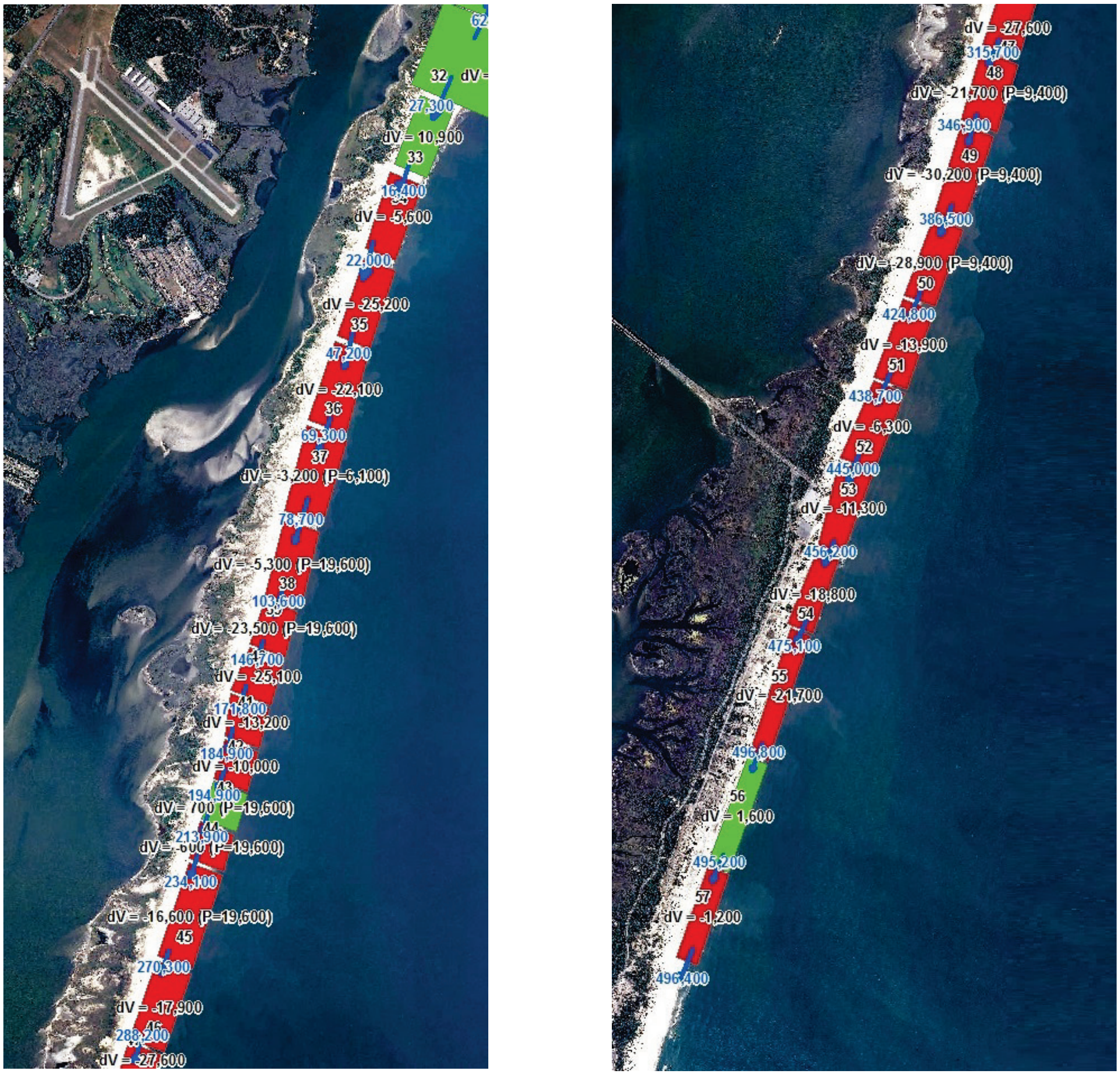
Figure 7. Ocean City Inlet sediment budget: Fall 2008–Fall 2013 epoch.

Table 1. Ocean City Inlet sediment budget: Fall 2008–Fall 2013 epoch.

SBAS Cell	Overall Volumetric Change (yd^3)	Overall Volumetric Change (yd^3/yr)	Removal (yd^3)	Adjusted Volume Change (yd^3)	Adjusted Rate of Change (yd^3/yr)
28	-247,500	-49,500	412,100[1]	164,500	32,900
29	-83,000	-16,600	0	-83,000	-16,600
30	-138,000	-27,600	273,200	135,500	27,100
31	310,500	62,100	0	310,500	62,100
32	245,500	49,100	0	245,500	49,100

[1] 413,200 yd^3 were initially dredged from Cell 28, but 1,060 yd^3 were subsequently returned to the cell.

Figure 8 shows the sediment budget for Assateague Island and that all transport is south. The sediment budget includes placement of approximately 132,400 yd^3/yr of material including 45,300 yd^3/yr into the north placement area (Cells 37 to 39), and 58,900 yd^3/yr and 28,200 yd^3/yr placed into the south placement areas of Cells 42 to 45, and Cells 48 to 50, respectively. Figure 8 correlates with Figure 5, where most of the Assateague Island cells showed volume losses over the epoch with only positive volume change in Cell 33 on the northern end of Assateague Island and in Cells 43 and 56. A 496,400 yd^3/yr transport rate leaving the southern boundary of the study area was derived from the analysis; however, no overwash was considered due to the absence of lidar data.



a **b**

Figure 8. Upper (a) and lower (b) Assateague Island sediment budget: Fall 2008–Fall 2013 epoch.

DISCUSSION: Table 2 lists volume change rate of the inlet cells compared to corresponding cells of two previous epochs that were presented by OCTI (2011). The rates in Table 1 were adjusted for dredging activities to gain an understanding of volume change of the natural system. The ebb-shoal growth rate (Cell 28) was much greater during the 2004–2008 epoch than the previous epoch of 1995–2002, which OCTI (2011) found consistent with observations of Buttolph et al. (2006). Buttolph noted radial expansion of the ebb shoal in response to the rehabilitation of the outer leg of the south jetty. However, the growth rate decreased to 32,900 yd^3/yr in the recent 2008–2013 epoch. Similar volume change rates are noted between the two most recent epochs in Cell 30, between the jetties and in the inlet, and in Cell 32 on Assateague Island, although the growth rate in Cell 32 of these epochs is nearly half of what was

observed during the 1995–2002 epoch. The northernmost cell on Assateague Island showed a positive volume change rate during 2008–2013, whereas the previous two epochs showed losses. There was no comparable Cell 29, located between Assateague Island and the ebb shoal, for the previous two epochs. The sum of volume change in the inlet cells is similar between the 2004–2008 and 2008–2013 epochs, approximately 168,000 yd^3/yr and 154,600 yd^3/yr, respectively, but the locations of volume change differ.

Table 2. Volume change rates in Ocean City Inlet.

Cell	Epoch		
	2008–2013 (yd^3/yr)	2004–2008 (yd^3/yr)	1995–2002 (yd^3/yr)
28	32,900	142,700	17,300
29	-16,600	-	-
30	27,100	24,900	13,100
31	62,000	-53,600	-2,200
32	49,100	54,100	91,800

The southern end loss on Assateague Island during the 2008–2013 epoch (496,400 yd^3/yr) is greater than observed losses during the 2004–2008 epoch (384,000 yd^3/yr) and the 1995–2002 epoch (363,900 yd^3/yr). The increased loss rate is most likely attributed to the growth of the ebb shoal which trapped much of the material that would have been transported to the southern end of the island. A nodal point in which longshore transport diverges was observed on Assateague Island for the 2004–2008 epoch but was not present in the 2008–2013 nor the 1995–2002 epochs.

Ideally, the volume removed from the inlet for beach placement should balance with no net gain or loss. One of the difficulties in finding this balance is the uncertainty of the sediment fluxes and directions. Fluxes from previous epochs were used as a guide for the 2008–2013 epoch. For example, it is not known if sediment is backpassing from northern Assateague Island into the channel. A greater understanding of these fluxes could be gained through modeling the hydrodynamics and sediment pathways.

CONCLUSIONS: This CHETN documents the purpose, development, and outcomes of the second tier in the Atlantic Coast of Maryland Sediment Budget Update as part of a greater plan to develop a regional sediment budget for the mid-Atlantic coastal zone. It is recommended that two-dimensional hydrodynamic and sediment transport modeling, such as a Particle Tracking Model, be performed in the region to gain a better understanding of the sediment pathways and sources and sinks of sediment. Other areas of future study could involve investigating the cause of the erosional trend evident at the southern end of the project. In particular, the possibility of wave interaction with the ebb shoal could be explored to determine if it detrimentally affects the adjacent beach. Additionally, the reduction of overwash during storm events also could be explored to reduce maintenance dredging in the Federally authorized navigation channels. This would require data collection necessary to quantify the overwash influence on the sediment budget.

ADDITIONAL INFORMATION: This CHETN was prepared by Ernest R. Smith (*Ernest.R.Smith@usace.army.mil*), ERDC, Vicksburg, MS; Joseph C. Reed (*Joseph.C.Reed@usace.army.mil*); and Ian L. Delwiche (*Ian.L.Delwiche@usace.army.mil*), USACE NAB. The

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> Smith, E. R., J. C. Reed, and I. L. Delwiche. 2016. *The Atlantic Coast of Maryland, sediment budget update: Tier 2, Assateague Island and Ocean City Inlet*. ERDC/CHL CHETN-XIV-48. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

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